UNDERWATER SOUND PROPAGATION IN TONKIN GULF AND ITS APPLICATION FOR COMMUNICATION

Truyền âm dưới nước trong vịnh Bắc Bộ và áp dụng cho truyền tin

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Tóm tắt- Bài toán truyền âm dưới nước là một bài toán phức tạp vì đa phần các trường hợp ta không có đủ kiến thức định lượng (cả về lý thuyết và thực nghiệm) về các đại lượng cần để dự đoán kênh truyền cự ly xa. Trong bài toán truyền âm biển ta phải xét đến các điều kiện mặt, đáy biển và cả tính chất các lớp nước. Ngoài các điều kiện trên biến đổi theo không gian còn các điều kiện hải dương học biến đổi theo thời gian. Bài báo này giải bài toán truyền âm biển ở vịnh Bắc Bộ vào mùa Đông dùng phương pháp lý thuyết truyền sóng. Từ đó xây dựng mô hình đáp ứng xung và phân bố kênh của vịnh Bắc Bộ. Một số kết quả dùng mô hình kênh đề xuất kết hợp điều chế không gian được giới thiệu.

Từ khóa: *Truyền âm dưới nước,vịnh Bắc Bộ, điều chế không gian*

Abstract-Underwater sound propagation (USP) is a complicated problem since in almost cases we do not have enough knowledge (both in theory and experiments) on required parameters for long range channel estimations. In USP problem we must consider features of ocean surface, bottom as well as water column properties. Those quantities are varying in space whereas oceanographic quantities changing in time. This paper solve USP problem in Tonkin gulf in winter using wave propagation theory. From that it is defined the impulse response (IR) and the distribution of the underwater sound channel (USC) in Tonkin gulf. Some results using proposed USC combining space modulation(SM) are shown.

Keywords: Underwater sound propagation, Tonkin gulf, space modulation

I.PROBLEM FORMULATION

Underwater sound propagation (USP) is investigated intensively in [1-4]. However, USP is a complicated problem since in almost cases we do not have enough knowledge (both in theory and experiments) on required parameters for long range channel estimations. In USP problem we must consider features of ocean surface, bottom as well as water column properties. Those quantities have varying in space whereas oceanographic quantities changing in time.

The USP problem in Tonkin gulf could be declared in the following

a/Given a manmade sound source located near the surface

b/ Ocean surface and bottom are flat and parallel

c/ Ocean deep is less than 100 m

d/ Water column is stratified with its given density $\rho(z)$ and sound speed $c(z)$ (depending on deep, z).

e/ At ocean surface and bottom the sound pressure is vanished. If there are bottom penetrations then acoustic rays will be energy losses.

f/ Reflections at ocean surface are energy lossless, only phase rotation (180^0 degree).

g/Reflections at ocean bottom (the density $\rho_1 = 2000 kg/m^3$, the sound speed $c_1 = 1700 m/s$) can be energy losses depending on the bottom properties (sand, mud., etc)

h/Sound scattering caused by sponges layers, marine organism is not considered in this problem (since in this case it is assumption of using a long sound wave).

The solution of the problem is finding the acoustic potential. In general the acoustic potential can be acoustic pressure potential (P), particle velocity displacement potential (V) and particle displacement potential (ψ). In this paper we use acoustic pressure potential (P) for instance.

The paper is organized as follows. Wave propagation theory is presented in part II. Part III introduces underwater acoustic field in Tonkin gulf. The impulse response and the distribution of USC in Tonkin gulf is discussed next. Some results of using suggested USC in Tonkin gulf combining space modulation are shown in part V. Finally, we conclude the paper.

II.WAVE PROPAGATION THEORY

To solve USP problem, we start from Helmholtz equation in an inhomogeneous medium which is given by [1]

$$[\nabla^2 + k^2(\bar{r})]\,\psi(\bar{r},\omega) = 0 \qquad (1)$$

where $k(\bar{r}) = \dfrac{\omega}{c(\bar{r})}$ is wave number in a stratified medium and ψ is acoustic pressure potential.

Since there is a sound source (a point source) in the medium, so (1) can be written as

$$[\nabla^2 + k^2(\bar{r})]\,\psi(\bar{r},\omega) = S_\omega \delta(\bar{r} - \bar{r}_0) \qquad (2)$$

where S_ω is the source strength, $\bar{r}_0$ is the source position.

The radiation condition is

$$R[\frac{\partial}{\partial R} - ik]\psi(\bar{r}_0) \to 0, R = \left|\bar{r} - \bar{r}_0\right| \to 0 \qquad (3)$$

The boundary conditions are give by

$$B[\psi(\bar{r})]\Big|_{z=z_n} = 0, n = 0, H \qquad (4)$$

where n=0 for ocean surface, n=H for ocean bottom.

The solution of (1) using integral transform method [1] is given by

$$\psi(k_r, z) = S_\omega[\frac{\exp(ik_z|z - z_s|)}{4\pi ik_z} - \frac{\exp(ik_z|z + z_s|)}{4\pi ik_z}] \quad (5)$$

where k_z is vertical wave number, z_s is the source position.

Underwater acoustic field at a receiver is a superposition of acoustic pressure potentials and has its amplitude spectrum varying in vertical wave numbers. Their minimums are obtained as

$$k_z = \frac{(m-1)}{z_s}\pi, m = 1, 2... \quad (6)$$

Their maximum are obtained as

$$k_z = \frac{(2m-1)}{2z_s}\pi, m = 1, 2... \quad (7)$$

III. UNDERWATER ACOUSTIC FIELD IN TONKIN GULF

Underwater acoustic properties of Tonkin gulf follows the underwater acoustic features of a shallow water in the world (the deep is less than 200m). However the particular features of Tonkin gulf are given in Table I as follows

Table I. The underwater acoustic parameters of Tonkin gulf

Parameter	**Value**
Ocean deep	$z \le 50$ m, H=50m
Sound speed in winter	$c(z) = 1510 + 0.3z$
Bottom construction from 10 knot to the coast	Sand, $\rho_1 = 2000kg/m^3, c_1 = 1700m/s$
Air properties at ocean surface	$\rho_k = 12kg/m^3, c_k = 340m/s$

The parameters in Table I, especially sound speed is from [5].

The wave equation is solved using boundary conditions (ocean surface, bottom) as in Table I as well as the deep of water column, H and a point source (transmitter and receiver) located near the ocean surface ($z_s \le 10$ m). It is defined the typical underwater sound propagation in winter as in Figure 1.

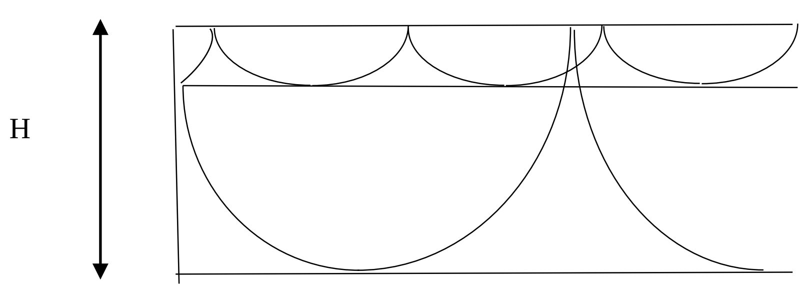

Figure 1. Underwater sound propagation in winter

Observation the underwater sound propagation in Figure 1 we see that ocean surface and bottom reflections are manifested. There are acoustic rays bending caused by sound speed varying in water column. Although the acoustic rays are reflected many times at the surface they are energy lossless. The acoustic rays reflected at ocean bottom could be loss half their powers each time since energy penetration phenomenon.

IV.THE IMPULSE RESPONSE AND THE DISTRIBUTION OF UNDERWATER SOUND CHANNEL IN TONKIN GULF

As we known, an impulse response (IR) of a channel in general, completely describes that channel [6]. Known the IR of a channel means that known the channel. From wave propagation theory in part II and underwater acoustic field in Tonkin gulf in part III we induce some significant features of sound propagation in the channel as follows:

Noting that in the winter, if a sound source is located near ocean surface, it is likely to form a sound surface channel. In this cases, 3 ray groups are created if sound waves emitted from the source with large cone. These ray groups are classified into:

Group 1: Surface upward rays are suffered multiple reflections at ocean surface ($h_1(t)$)

Group 2: Bottom reflected rays are suffered refracted from the water columns, possibly reflected at the bottom and lose their energy partially. ($h_3(t)$)

Group 3: Grazing rays (direct path) only reflected from the water column ($h_2(t)$)

With sound speed profile of Tonkin gulf, we see that the gradient is not high so the slope of refracted rays could be low. It is evident with high possibility there exists grazing rays in this channel.

On the time order, group 1 arrives first, then group 2 and group 3. On the amplitude, group 3 has highest values, then group 1 and group 3.

In summary, the IR of USC in Tonkin gulf has a mathematical form as follows

$$h(t) = h_1(t-a) + h_2(t-b) + h_3(t-c) \qquad (8)$$

Where $a < b < c$; $|h_3| < |h_1| < |h_2|$

The IR of USC in Tonkin gulf is depicted in Figure 2.

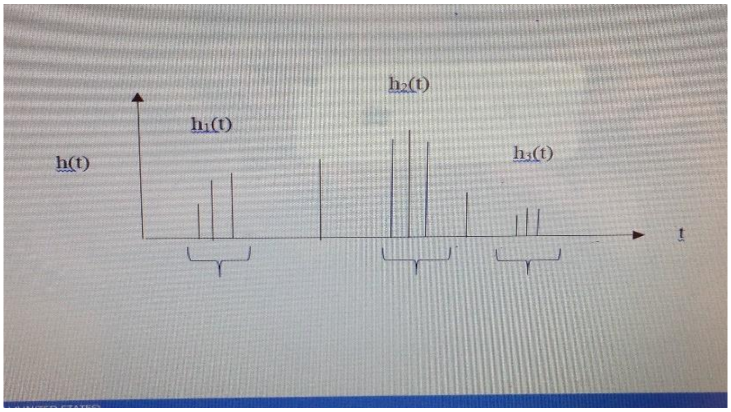

Figure 2. The IR of USC in Tonkin gulf

On the observation of (8), this is exactly the case of Rice distribution (There is an overwhelmingly ray group (i.e. grazing rays) around other contributions of Gaussian distributions).

Therefore, the distribution of acoustic intensity in Tonkin gulf is given by

$$W(I) = \frac{I}{\sigma^2}\exp(-\frac{(I^2+a^2)}{2\sigma^2})I_0 \qquad (9)$$

where $\sigma \geq 0$ is standard deviation, a is a distance from the origin to the centre of the distribution.

V. USING SUGGESTED USC IN TONKIN GULF COMBINING SPACE MODULATION

Space modulation is presented firstly in [7]. Then the application of SM in USC is introduced in [8]. If we use SM for USC with basic BPSK (m=1), 2 transmitting antennas and 2 receiving antennas ($N_t = N_r = 2$), the effective modulated symbol is given by

$$m_1 = m + \log_2 N_t = 1 + \log_2 2 = 2 \qquad (10).$$

Therefore using SM in USC we reduce twice the required bandwidth compared to QPSK.

The mapping of SM is given in Table II as follows

Table II. Space modulation mapping

$N_t = 2, M = 2$ **(Number of transmitted symbols)**		
Input bit	**Antenna index**	**Transmitted symbol**

00	1	-1
01	1	+1
10	2	-1
11	2	+1

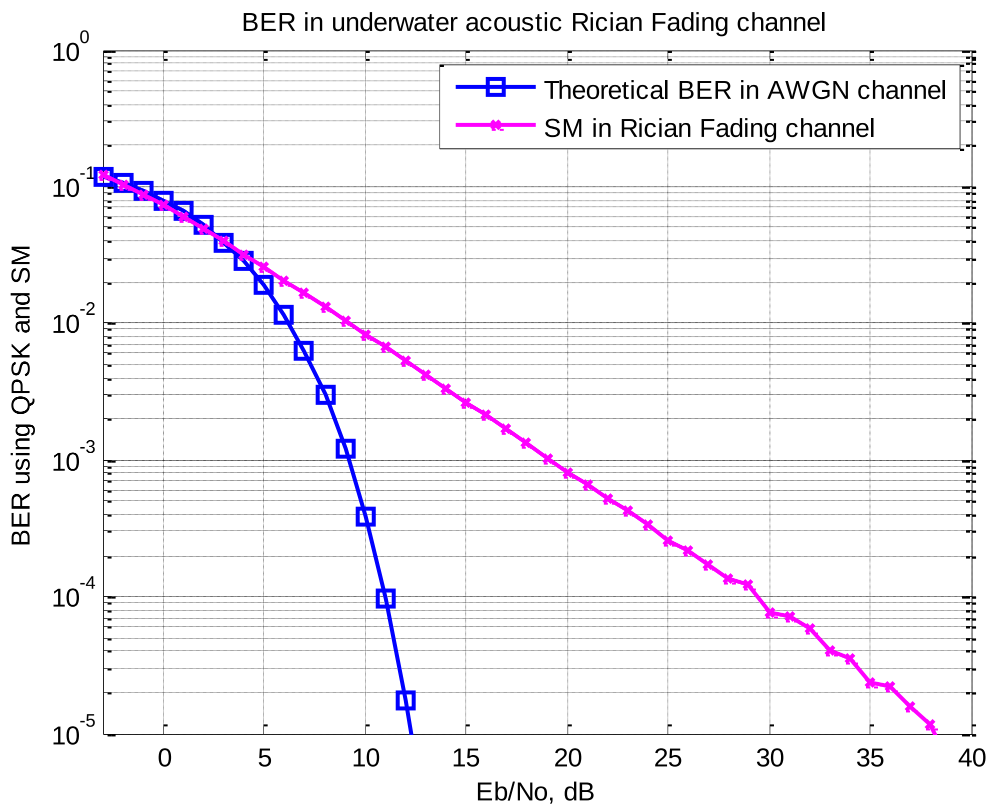

***Figure 3.**. BER for QPSK in AWGN USC (blue line) and Rich scattering Rice USC (Red line), a=1*

For Tonkin gulf in winter the results of using QPSK and SM are given in Figure 3. In this case the Rice distribution with *a*=1 is used for simulation. At BER=10^{-3} Rice channel is penalty of nearly 10 dB comparable to AWGN channel. When *a* is small the channel distribution being likely Rayleigh distribution which is investigated in [8] (for more detail about this distribution the reader can find in the paper).

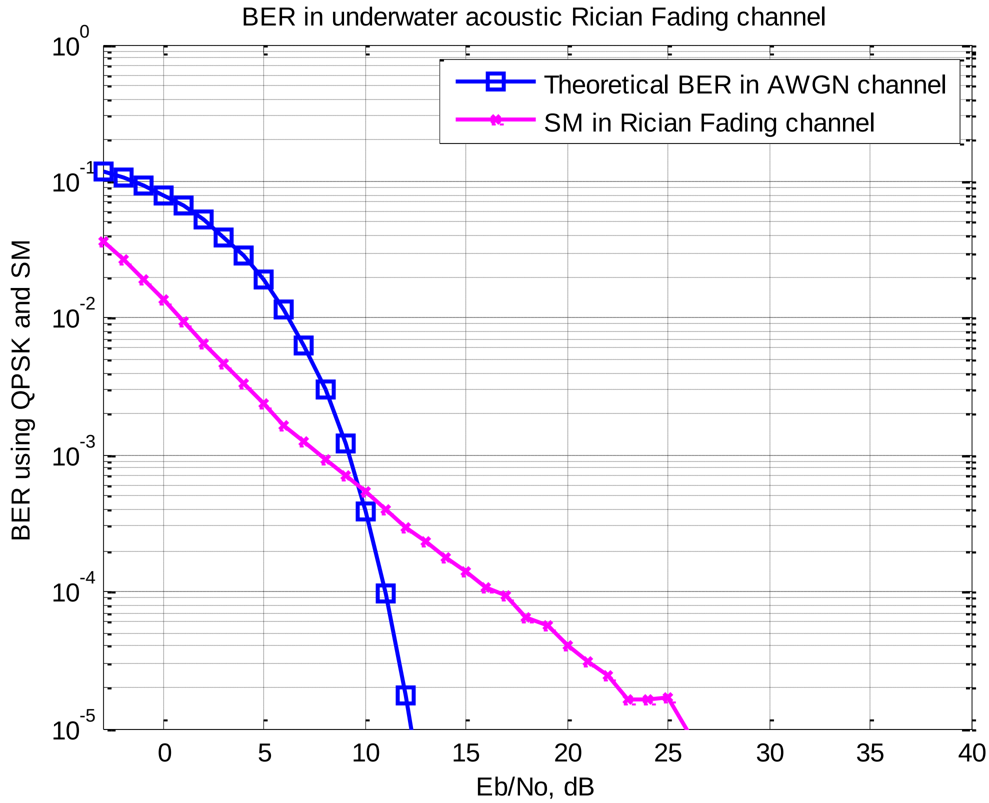

Figure 4. *BER for QPSK in AWGN USC (blue line) and Rich scattering Rice USC (Red line),a=2*

For Tonkin gulf in winter the results of using QPSK and SM are also given in Figure 4. However, in this case the Rice distribution with *a*=2 is used for simulation. At BER=10^{-3} Rice channel is comparable to AWGN channel. Therefore the quality of the USC become better remarkable (10 dB increment for the case with *a*=1) if the grazing rays group dominating other rays groups. For higher BER Rice channel is suffering more distortion which caused more BER at the receiver.

VI. CONCLUTIONS

The underwater sound propagation problem in Tonkin gulf is introduced. The problem is solved using wave propagation theory. Then it is defined the impulse response and the distribution of USC in Tonkin gulf. The results using proposed USC combining space modulation (SM) pointed out that the USC following the Rician fading, especially the quality of the USC become better remarkable if the grazing rays group dominating other rays groups.

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